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Abstract: This study examined changes in performance in age-group track runners across years from 1975 to 2015 for 100, 200, 400, 800, 1500, 5000, 10 000 m, and marathon and the corresponding sex differences. Athletes were ranked in 5-year age-group intervals from 35-39 to 95-99 years. For all races and all years, the eight female and male finalists for each age-group were included. Men were faster than women and this observation was more pronounced in the shorter distances. The younger age-groups were faster than the older age-groups and age exerted the largest effect on speed in 800 m and the smallest in marathon. There was a small variation of speed by calendar years. The competition density varied by sex and race distance. Half of participants were from USA, Germany, Australia, and Great Britain, but the participants' nationality varied by sex and race distance. In summary, the variation of competitiveness by sex in short race distances might be important for athletes and coaches. Considering the event's competitiveness and that athletes are participating in both 100 and 200 m or in 200 and 400 m, master women should be oriented to 200 m and master men should be oriented to 100 and 400 m.

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Performance trends in age group runners from 100m to marathon – The World Championships from 1975 to 2015

Performance of age group track runners

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Abstract

This study examined changes in performance in age group track runners across years from 1975 to 2015 for 100m, 200m, 400m, 800m, 1,500m, 5,000m, 10,000m and marathon and the corresponding sex differences. Athletes were ranked in 5-year age group intervals from 35-39 to 95-99 years. For all races and all years, the eight female and male finalists for each age group were included. Men were faster than women and this observation was more pronounced in the shorter distances. The younger age groups were faster than the older age groups and age exerted the largest effect on speed in 800m and the smallest in marathon. There was a small variation of speed by calendar years. The competition density varied by sex and race distance. Half of participants were from USA, Germany, Australia and Great Britain, but the participants' nationality varied by sex and race distance. In summary, the variation of competitiveness by sex in short race distances might be important for athletes and coaches. Considering the event's competitiveness and that athletes are participating in both 100m and 200m or in 200m and 400m, master women should be oriented to 200m and master men should be oriented to 100m and 400m.

Key words: age, sex, master athletes, running

Introduction

It is well investigated that the world records in running are nearing their limits (Nevill and Whyte 2005) and elite men are running faster than elite women (Weiss et al. 2016). However, we have only very limited knowledge about the changes in performance in the last decades in age group runners (*i.e.* master runners older than 35 years) in track running (Akkari et al. 2015).

In other sports disciplines such as pool swimming, master athletes increased participation and improved performance in freestyle (Knechtle et al. 2016a), breaststroke (Knechtle et al. 2016b) and backstroke (Unterweger et al. 2016) swimming. Interestingly, older women (*i.e.* older than 80-90 years) were not slower than older men (Knechtle et al. 2016a, 2016b, Unterweger et al. 2016).

Participation and performance trends in running were mainly investigated for marathon running where preferably large city marathons such as the 'New York City Marathon' and other races of the 'World Marathon Majors' were analysed (Jokl et al. 2004, Lepers and Cattagni 2012). Several studies demonstrated that female and male master runners increased participation (Ahmadyar et al. 2015, Jokl et al. 2004, Knechtle et al. 2015, Lepers and Cattagni 2012) and improved performance (Ahmadyar et al. 2015, Jokl et al. 2004, Lepers and Cattagni 2012) in marathon running compared to younger age groups. For the top ten male and female age group marathoners aged between 20 and 79 years competing in the 'New York City Marathon' between 1980 and 2009 the participation of master runners increased to a greater extent for females compared to males (Lepers and Cattagni 2012). Running times of master runners significantly decreased for males older than 64 years and for females older than 44 years, respectively. Sex differences in running times decreased over the last three decades but remained relatively stable across the ages during the last decade (Lepers and Cattagni 2012).

For older marathoners (*i.e.* older than 75 years), the findings were different. In female and male marathoners older than 75 years competing during 2004-2011 in four races (*i.e.* Berlin, New York, Chicago and Boston) of the 'World Marathon Majors', participation for female and male runners remained unchanged and the fastest women and men became slower across years (Ahmadyar et al. 2016).

There is one study investigating the progression of athletic performance between 1975 and 2013 in older master athletes for 100m and 400m track running (Akkari et al. 2015) but data for trends in performance in age group runners in track running from 100m to 10,000m at world class level are missing. Therefore, the aim of this study was to investigate performance trends in elite age groups runners competing in track running from 100m to 10,000m and marathon road running at world class level. We hypothesized, based on analyses from marathon road running, that elite age group runners competing at world class level would improve performance in all running distances for 100m, 200m, 400m, 800m, 1,500m, 5,000m, 10,000m, and marathon road running.

Materials and Methods

Ethics approval

This study was approved by the Institutional Review Board of Kanton St. Gallen, Switzerland, with a waiver of the requirement for informed consent of the participants as the study involved the analysis of publicly available data.

Data sampling and data analysis

Data were obtained from the website of 'World Master Athletics' www.world-masters-athletics.org. We considered the data for women and men competing in the distances 100m, 200m, 400m, 800m, 1,500m, 5,000m, 10,000m, and marathon. Athletes were ranked in 5-year age group intervals from 35-39 to 95-99 years. For all races and all years, the eight female and male finalists for each age group were included and the eight fastest female and male marathoners. The races were held 1975 in Toronto (Canada), 1977 in Gothenburg (Sweden), 1979 in Hannover (Germany), 1981 in Christchurch (New Zealand), 1983 in San Juan (Puerto Rico), 1985 in Rom (Italy), 1987 in Montreal (Canada), 1989 in Eugene (USA), 1991 in Turku (Finland), 1995 in Buffalo (USA), 1997 in Durban (South Africa), 1999 in Gateshead (Great Britain), 2001 in Brisbane (Australia), 2003 in Carolina (Puerto Rico), 2005 in San Sebastian (Spain), 2007 in Riccione (Italy), 2009 in Lahti (Finland), 2011 in Sacramento (USA), 2013 in Porto Alegre (Brazil), an 2015 in Lyon (France).

Statistical analysis

The statistical software IBM SPSS v.23.0 (SPSS, Chicago, USA) performed all statistical analyses. Mean values and standard deviation (s) were calculated for all variables. A two-way analysis of variance (ANOVA) compared effects of sex, race distance, age group and calendar year on speed. Subsequent comparisons among race distances, age groups or calendar years were carried out using post-hoc Bonferroni test. The magnitude of these differences was examined using effect size eta squared (η^2) and evaluated as: small ($0.010<\eta^2\leq0.059$), moderate ($0.059<\eta^2\leq0.138$) and large ($\eta^2>0.138$) (Cohen, 1988). We analysed the relationship between speed and race duration using a logarithmic regression model. In addition, we examined sex differences in speed using the formula 100×(men's speed–women's speed)/women's speed. We also compared variations in speed by participants' sex, age group, race distance and calendar year by a mixed-effects regression model. In this model, participants were assigned as random variable, whereas sex, age group, race distance and calendar year were assigned as fixed variables. We examined interaction effects among these fixed variables. Akaike information criterion (AIC) was used to select the final model. These analyses were performed for each race distance (*i.e.* 100m, 200m, 400m, 800m, 1,500m, 5,000m, 10,000m and marathon) separately. A regression analysis of cubic degree was performed between speed and calendar year, and coefficient of determination (r^2) was calculated. In addition, the coefficient of density (CD)was calculated for each race distance by sex from the formula $CD=n_{finish}/(t_{last}-t_{first})$, where n_{finish} the number of participants in the race, t_{last} the race time of the last participant and t_{first} the race time of the first participant. Statistical significance was set at alpha=0.05.

Results

Performance by sex and race distance

According to the two-way ANOVA, a moderate main effect of sex on running speed was observed ($p<0.001$, $\eta^2=0.109$), where men were faster than women (Figure 1). Also, a large main effect of race distance on running speed was shown ($p<0.001$, $\eta^2=0.584$), where running speed in short distances was faster than longer distances. In addition, a trivial sex×race distance interaction on running speed was noticed ($p<0.001$, $\eta^2=0.004$) for all distances, too, with the sex difference being larger in the shorter race distances. These findings were in agreement with the mixed-effects regression analysis (main effect of sex coefficient (C)=-2.36, standard error of estimate (SEE)=0.17, p<0.001; main effect of race distance C<0.01, SEE<0.01, p<0.001; sex×race distance C<0.01, SEE<0.01, p=0.795). With regards to the association between running speed and race duration, an almost perfect ($r^2=\sim0.93$) logarithm relationship was observed (Figure 2). This relationship was of similar magnitude for both women and men.

Performance by sex and age group

A large main effect of sex on running speed ($p<0.001$), where men were faster than women, was observed for all race distances with η^2 ranging from 0.228 (100m) till 0.580 (5,000m) (Figure 3). In addition, a large main effect of age group on running speed ($p<0.001$), where athletes in the younger groups were running faster than athletes in the older one, was shown for all distances with η^2 ranging from 0.647 (marathon) till 0.878 (800m). A small sex×age group interaction on running speed ($p\leq0.026$), where the sex difference was larger in the younger age groups, was noticed for all race distances, too, with η^2 ranging from 0.009 (100m) till 0.024 (1,500m). The findings of the mixed-effects regression analysis were shown in Table 1.

Performance by sex between 1975 and 2015

A small main effect of calendar year on speed was observed in 100m, 200m, 1,500m, 10,000m and marathon ($p \leq 0.044$, $0.014 \leq \eta^2 \leq 0.050$), but not in 400m, 800m and 5,000m ($p \geq 0.160$, $\eta^2 \leq 0.011$) (Figure 4). A small calendar year×sex interaction on running speed ($p=0.038$, $\eta^2=0.013$) was shown for 200m, but not for the other distances. The findings of the mixed-effects regression analysis were presented in Table 2. The regression analysis of cubic degree between sex difference and calendar year showed variation by race distance: 100m ($r^2=0.43$), 200m ($r^2=0.63$), 400m ($r^2=0.56$), 800m ($r^2=0.67$), 1,500m ($r^2=0.46$), 5,000m ($r^2=0.59$), 10,000m ($r^2=0.50$) and marathon ($r^2=0.07$) (Supplement file). However, running speed in the most recent calendar year (2015) did not differ from 1975 in any race distance (-0.34, -0.54, -0.07, -1.21, +0.35, +0.19, -0.78 and +0.85 km/h in 100m, 200m, 400m, 800m, 1,500m, 5,000m, 10,000m and marathon, respectively).

Competition density

The competition density (CD) ranged from 0.04 (marathon) to 25.18 competitors/sec (100 m) in women and from 0.13 (marathon) to 21.43 competitors/sec (100 m) in men (Figure 5).

Competition by nationality

Overall, in both sexes, the four most prevalent nationalities were USA, Germany, Australia and Great Britain, consisting half of the overall participants (Supplement file). However, the distribution of nationalities by race distances showed a variation in women and men. In women, Germany and Australia showed a remarkable variation with a higher participation in the short distances and lower in the long distances, whereas the opposite trend was observed for the 'other' countries (*i.e.* the countries with less than 10 participants in at least two events). In men, athletes from USA and Germany were also more prevalent in short distances and lessin long distances, whereas the 'other' countries showed the opposite trend. It was remarkable that 43% of the overall men were either from USA or from Germany in 100m, whereas the respective percentage in marathon was 23%.

Discussion

The main findings of the present study were that (*i*) men were faster than women and this observation was more pronounced in the shorter distances, (*ii*) athletes in the younger age groups were faster than athletes in the older age groups and age exerted the largest effect on speed in 800 m and the smallest in marathon, (*iii*) there was a small variation of running speed by calendar years, (*iv*) the competition density varied by sex and race distance, and (*v*) half of the participants were from USA, Germany, Australia and Great Britain, but the participants' nationality varied by sex and race distance.

Master men were faster than master women

A first important finding was that men were faster than women and this observation was more pronounced in the shorter race distances. Generally, men are running faster than women when competing at both world class level (Nevill and Whyte 2005; Weiss et al. 2016) and at recreational level (Knechtle et al. 2015). The sex difference remained stable in running distances from 100m to the marathon in the last decades in elite athletes (Cheuvront et al. 2005, Sparling et al. 1998). However, this difference is most likely due to the number of selected athletes for an analysis because most running studies investigated generally a limited sample of the best athletes for each age group (Lepers and Cattagni 2012, Weiss et al. 2016). Thus, the superiority of men in running performance should not be accepted for true without questioning or testing it. Deaner (2013) argued that the dominance in men's performance in running is largely due to the larger participation in men in running races. It has been shown in age groups athletes competing in US Masters championships that that a participation-related relative age effect in masters sports is stronger for men, that it becomes progressively stronger with each successive decade of life (Medic et al. 2009). Also when running times of the first 10 placed men and women in the 5-year age groups between 20 and 79 years and the number of women and men who finished the 'New York City Marathon' between 1980-2010, the sex difference in running speed increased between the 1st and the 10th place due to a greater relative drop in velocity of women than men (Hunter and Stevens 2013). The sex difference increased with advanced age and decreased during the investigated time period but more for the older age groups. The number of women also increased relative to men during that period but more in the older age groups. The greater sex difference in running speed with increasing age and with increased place was primarily explained by the lower number of female than male finishers (Hunter and Stevens 2013). In the present study, however, we used only the eight finalists in track running and the eight fastest marathoners which might explain our findings for the different distances (*i.e.* men were faster than women in the shorter distances).

For other athletes such as age group swimmers, the findings were different. In freestyle (Knechtle et al. 2016a), breaststroke (Knechtle et al. 2016b) and backstroke (Unterweger et al. 2016) swimming, older women (*i.e.* older than 80-90 years) were not slower than older men. The most likely explanation for these disparate findings might be that in the present study the eight finalists were considered, whereas in the swimmers (Knechtle et al. 2016a, 2016b, Unterweger et al. 2016), all recorded athletes for each age group were considered. This is due to the fact that in master swimming at world class level, all swimmers competing in specific age groups are ranked (www.fina.org/discipline/masters) whereas in master running at world class level, heats and finals are held (www.world-masters-athletics.org) and only the finalists are recorded in the final rankings. Therefore, the sex difference in running performance observed in the present study should be attributed to a selection bias of participants (*i.e.* comparison between elite athletes in each age group).

Moreover, we observed a trivial variation of sex differences in running speed by distance, *i.e.* the longer the race distance, the lower the sex difference. This variation might be due to the different contribution of the three main energy transfer human systems (*i.e.* ATP-CP, anaerobic glycolysis and aerobic processes) in performance of running events varying for distance (Ross and Leveritt, 2001). Shorter distances, such as 100m and 200m, rely mostly on

ATP-CP and anaerobic glycolysis, whereas 10,000m and marathon rely mostly on aerobic processes. ATP-CP and anaerobic glycolysis collectively relate to anaerobic capacity, whereas aerobic processes associate with aerobic capacity (Trappe, 2007). Thus, the larger sex difference in anaerobic than in aerobic capacity might partially explain the decrease of sex difference as the running distance increases and *vice versa* (Galloway, Kadoko and Joki, 2002).

Athletes in younger age groups were faster than athletes in older age groups

A second important finding was that the athletes in the younger age groups were faster than the athletes in the older age groups and age exerted the largest effect on running speed in 800m and the smallest in marathon. The superiority of younger age groups should not be taken for granted as it has been shown that age of peak performance might vary by sex, performance level or race distance (Knechtle et al. 2016d). Age seems to have a different effect on running performance depending on race distance. For male elite sprinters, age was strongly related to 200m running performance (Maćkala et al. 2015). For both male and female master athletes, the 400m race was most affected by advancing age (Fung et Ha 1994).

Generally, younger runners are faster than older runners; however, the age of peak running performance seems to vary with race distance (Allen and Hopkins 2015). In adolescent athletes at the age of 11-18 years, male and female athletes perform almost equally in running and jumping events up to the age of 12 years. However, beyond this age, male athletes outperform female athletes (Tønnessen et al. 2015). It is important to note that the age of peak performance has changed in recent decades in female but not in male athletes. In the last 20-30 years, ages at which peak athletic performance is observed have increased in female but not in male athletes (Elmenshawy et al. 2015).

Small variation of speed by calendar years

A further important finding was that except three race distances (*i.e.*400m, 800m and 5,000m), a small effect of calendar year on running speed was observed. However, there was not any consistent trend through calendar years among race distances, and compared to 1975, running speed in 2015 was similar for all race distances. This observation was in agreement with the trend of world records in master athletes, where it was noticed that many world records in age groups were realized in 1990's and 2000's (www.world-masters-athletics.org). In addition, the lack of improvement of performance by calendar years might be partially attributed to the variation of the number and performance level of athletes in the meetings which were organized in all over the world.

The findings of our study differ to the findings in Akkari et al. (2015) where all the age-group records improved significantly over time in 100m and 400m running. The slopes of improvements over the years were progressively greater at older age groups (*i.e.* older than 45 years) with the greatest progression observed at oldest age groups of 75-79 years (Akkari et al. 2015).

Competition density varied by sex and race distance

The main finding with regards to CD was that 100m showed the highest density in both women and men, whereas marathon was the least dense in both sexes, *i.e.* the density decreased as race duration increased. This finding was in agreement with a study of 100m and 200m in Olympic Games and Paralympic Games between 1992 and 2012, where in both Games 200m were less dense than 100m (Grobler et al. 2015).

A secondary finding was a variation of CD by sex. Although we observed small sex differences in events longer than 800m, in shorter events CD differed between women and men. Particularly, 100m and 400m were denser for women, whereas 200m were denser for men.

The aspect of nationality

A further finding was that half of the participants were from USA, Germany, Australia and Great Britain, but the participants' nationality varied by sex and race distance. In running, the aspect of nationality has mainly been investigated for elite marathoners where the dominance of East African runners is well known (Marc et al. 2015). An actual study investigating the annual top 100 women and men competing in four races of the 'World Marathon Majors' (*i.e.* Boston, Berlin, Chicago and New York) and the 'Stockholm Marathon' between 2000 and 2014 showed that female and male marathoners from Ethiopia were the youngest and the fastest (Knechtle et al. 2016c).

Limitations

A limitation of the use of CD as a measure of competitiveness was the consideration of the large variation of race time among race distances. This measure offered valuable information about sex differences in competitiveness within the same race distance. However, the race distances differed largely in terms of race time, so the findings concerning the comparison of CD among race distances were the expected, *i.e.* the larger the race distance, the longer the race time and the less the CD.

Perspectives

In summary, men were running faster than women and this observation was more pronounced in the shorter race distances, athletes in the younger age groups were running faster than athletes in the older age groups and age exerted the largest effect on running speed in 800m and the smallest in marathon, the variation of running speed by calendar years was small, the competition density varied by sex and race distance, and half of participants were from USA, Germany, Australia and Great Britain, but the participants' nationality varied by sex and race distance. For athletes and coaches, the variation of competitiveness by sex in short distances might be important information for coaches and athletes. Considering event's competitiveness and that there are athletes participating in both 100m and 200m or in 200m and 400m, master women should be oriented to200m and master men should be oriented to 100m and 400m

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Table 1 Coefficients (C) and standard errors of estimate (SEE) from multi-variate regression models for race speed of participants by sex and age group for each race distance.

		C	SEE	*p*
100m	Sex	-5.78	0.18	<0.001
	Age group	-1.48	0.02	<0.001
	Interaction sex×age group	0.21	0.03	<0.001
200m	Sex	-5.61	0.17	<0.001
	Age group	-1.52	0.02	<0.001
	Interaction sex×age group	0.13	0.03	<0.001
400m	Sex	-5.94	0.16	<0.001
	Age group	-1.48	0.02	<0.001
	Interaction sex×age group	0.20	0.03	<0.001
800m	Sex	-5.21	0.13	<0.001
	Age group	-1.36	0.01	<0.001
	Interaction sex×age group	0.20	0.02	<0.001
1,500m	Sex	-5.00	0.12	<0.001
	Age group	-1.21	0.01	<0.001
	Interaction sex×age group	0.24	0.02	<0.001
5,000m	Sex	-6.17	1.56	<0.001
	Age group	-1.07	0.17	<0.001
	Interaction sex×age group	0.76	0.27	0.005
10,000m	Sex	-5.36	1.50	<0.001
	Age group	-0.96	0.17	<0.001
	Interaction sex×age group	0.70	0.27	0.010
Marathon	Sex	-3.39	1.29	<0.001
	Age group	-0.59	0.16	<0.001
	Interaction sex×age group	-0.01	0.26	0.972

Table 2 Coefficients (C) and standard errors of estimate (SEE) from multi-variate regression models for race speed of participants by sex and calendar year for each race distance.

		C	**SEE**	***p***
100m	Sex	27.04	32.26	0.402
	Calendar year	<0.01	0.01	0.706
	Interaction sex×calendar year	-0.01	0.02	0.354
200m	Sex	14.52	35.41	0.682
	Calendar year	<0.01	0.01	0.926
	Interaction sex×calendar year	-0.01	0.02	0.617
400m	Sex	-29.33	31.65	0.354
	Calendar year	-0.01	0.01	0.533
	Interaction sex×calendar year	0.01	0.02	0.408
800m	Sex	-47.42	29.40	0.107
	Calendar year	-0.02	0.01	0.020
	Interaction sex×calendar year	0.02	0.01	0.128
	Sex	-1.54	23.91	0.949
1,500m	Calendar year	-0.01	0.01	0.096
	Interaction sex×calendar year	<0.01	0.01	0.970
	Sex	-186.13	129.66	0.151
5,000m	Calendar year	-0.02	0.04	0.660
	Interaction sex×calendar year	0.09	0.06	0.154
	Sex	169.71	123.49	0.169
10,000m	Calendar year	-0.02	0.04	0.625
	Interaction sex×calendar year	-0.09	0.06	0.167
	Sex	155.52	104.20	0.136
Marathon	Calendar year	0.06	0.03	0.080
	Interaction sex×calendar year	-0.08	0.05	0.129

List of figures

Figure 1

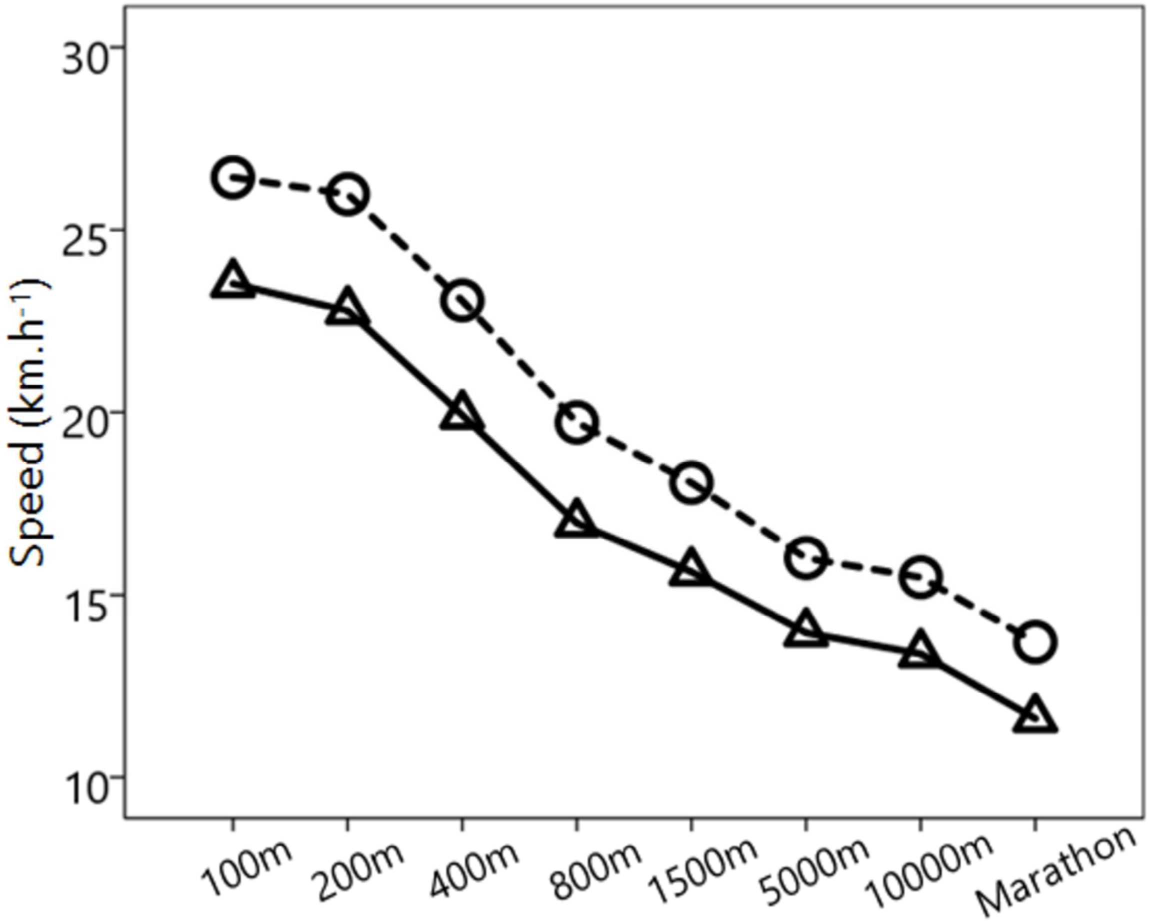

30
25
20
15
10
Speed (km.h-1)
100m
200m
400m
800m
1500m
5000m
10000m
Marathon

Figure 2

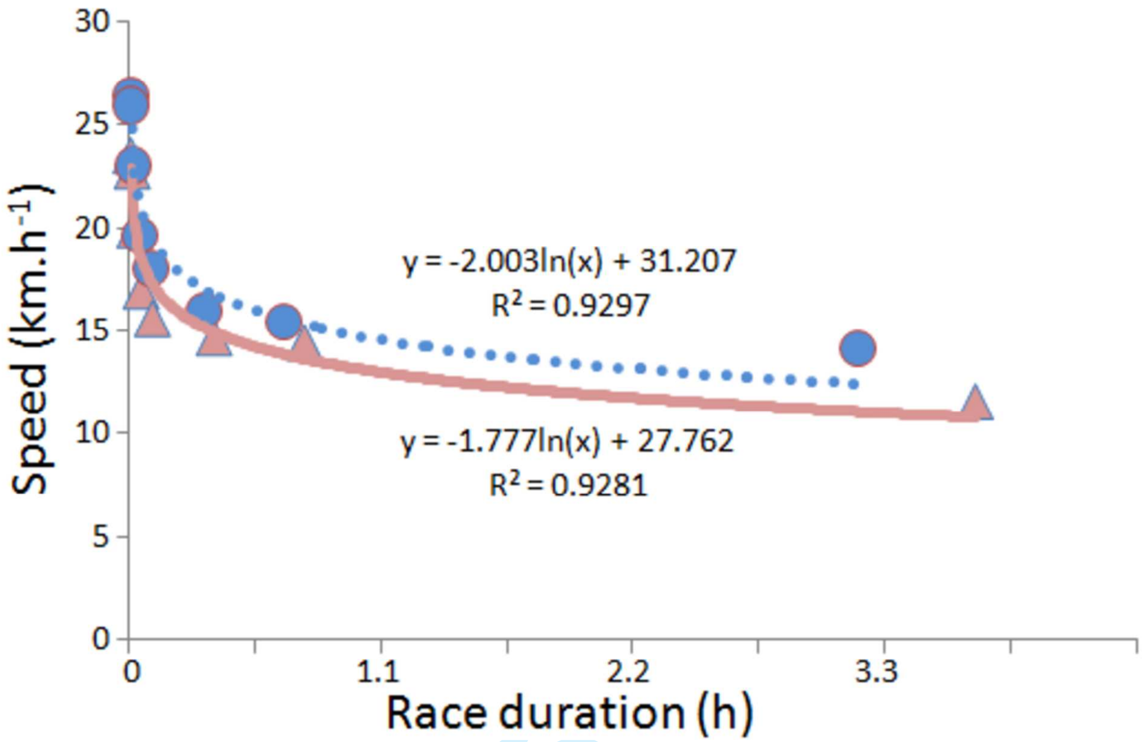

y = -2.003ln(x) + 31.207
R² = 0.9297
y = -1.777ln(x) + 27.762
R² = 0.9281
Speed (km.h-1)
Race duration (h)
30
25
20
15
10
5
0
0
1.1
2.2
3.3

Figure 3

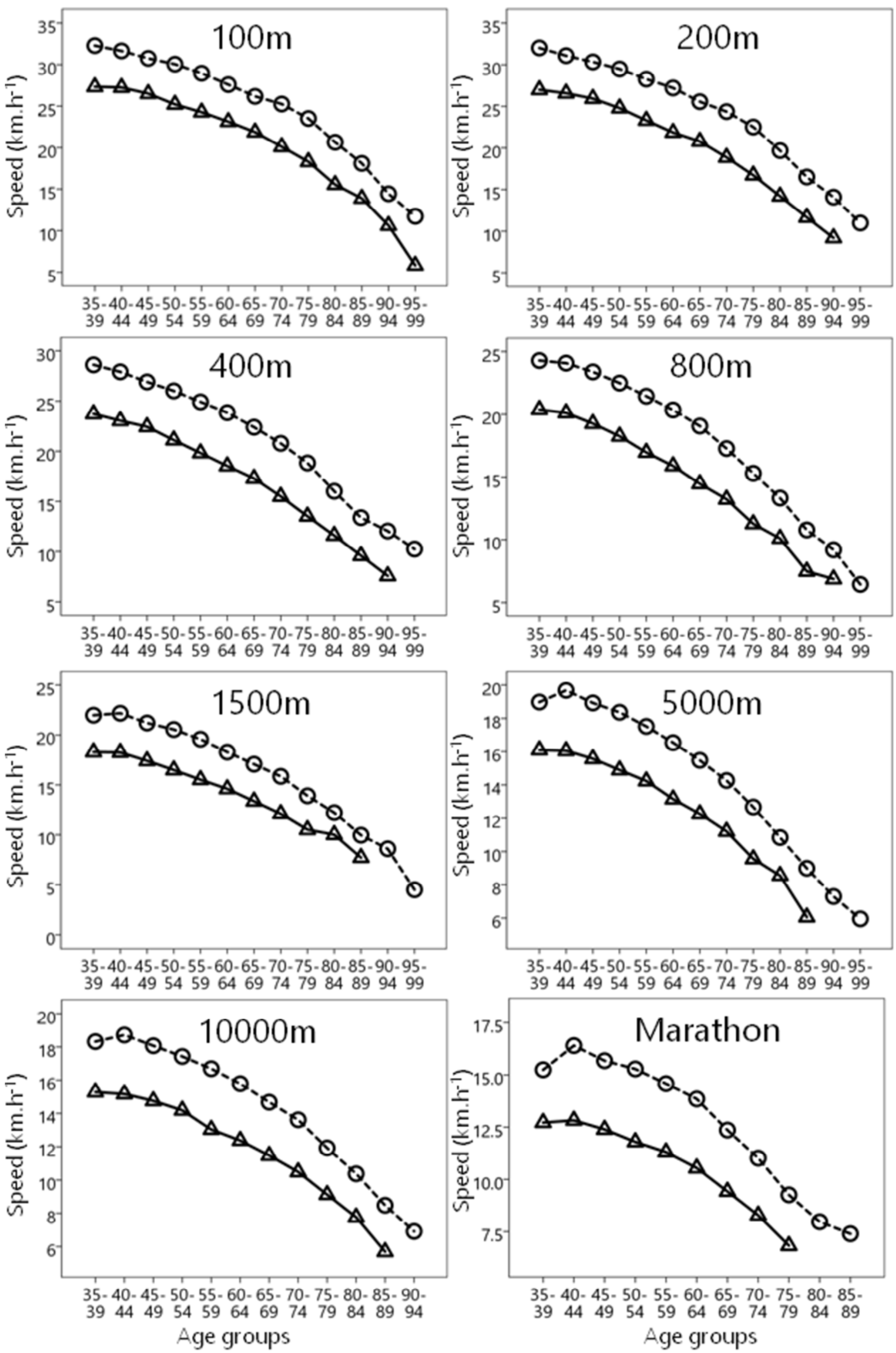

100m
200m
400m
800m
1500m
5000m
10000m
Marathon
Speed (km.h-1)
Age groups
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90-94
95-99

Figure 4

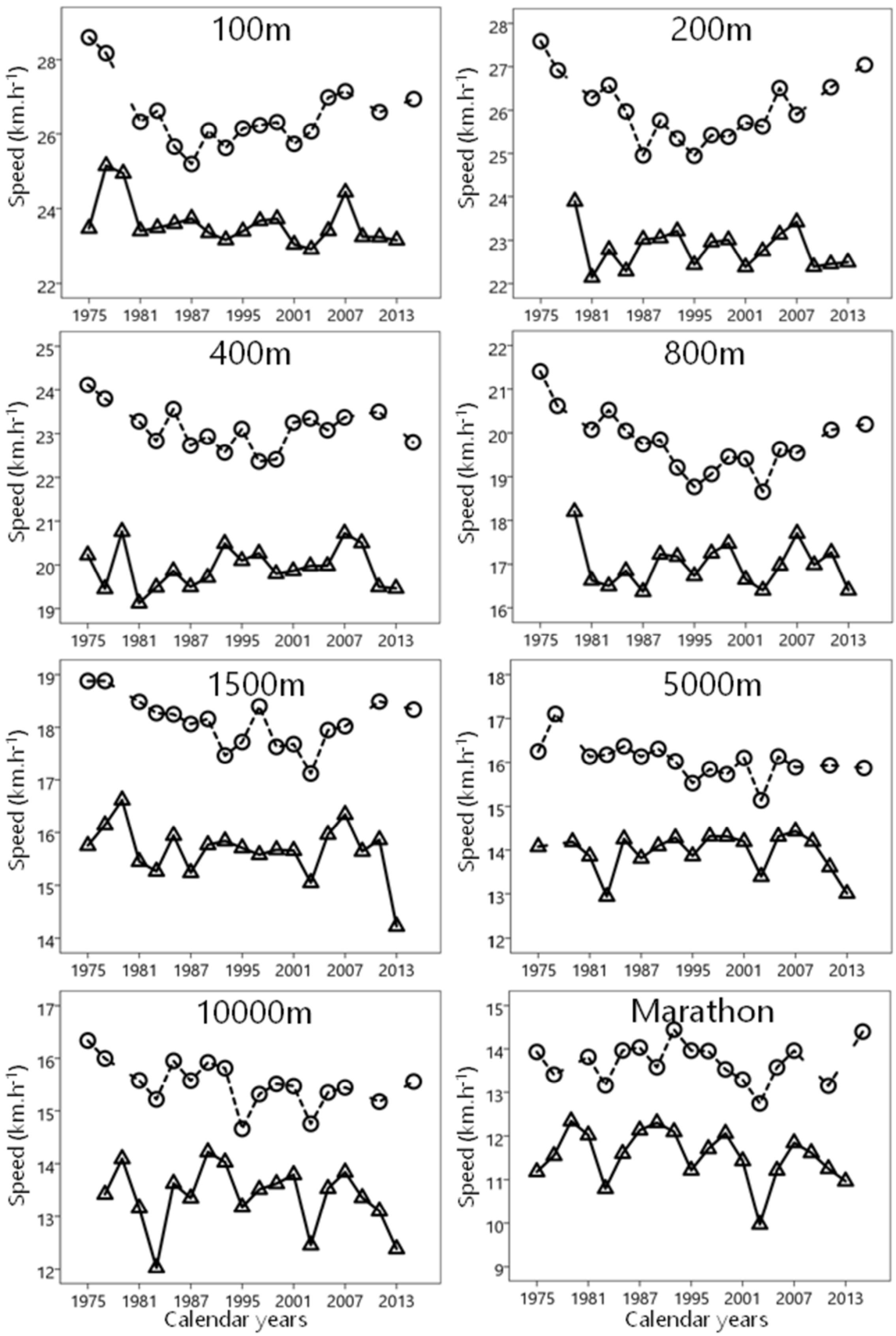
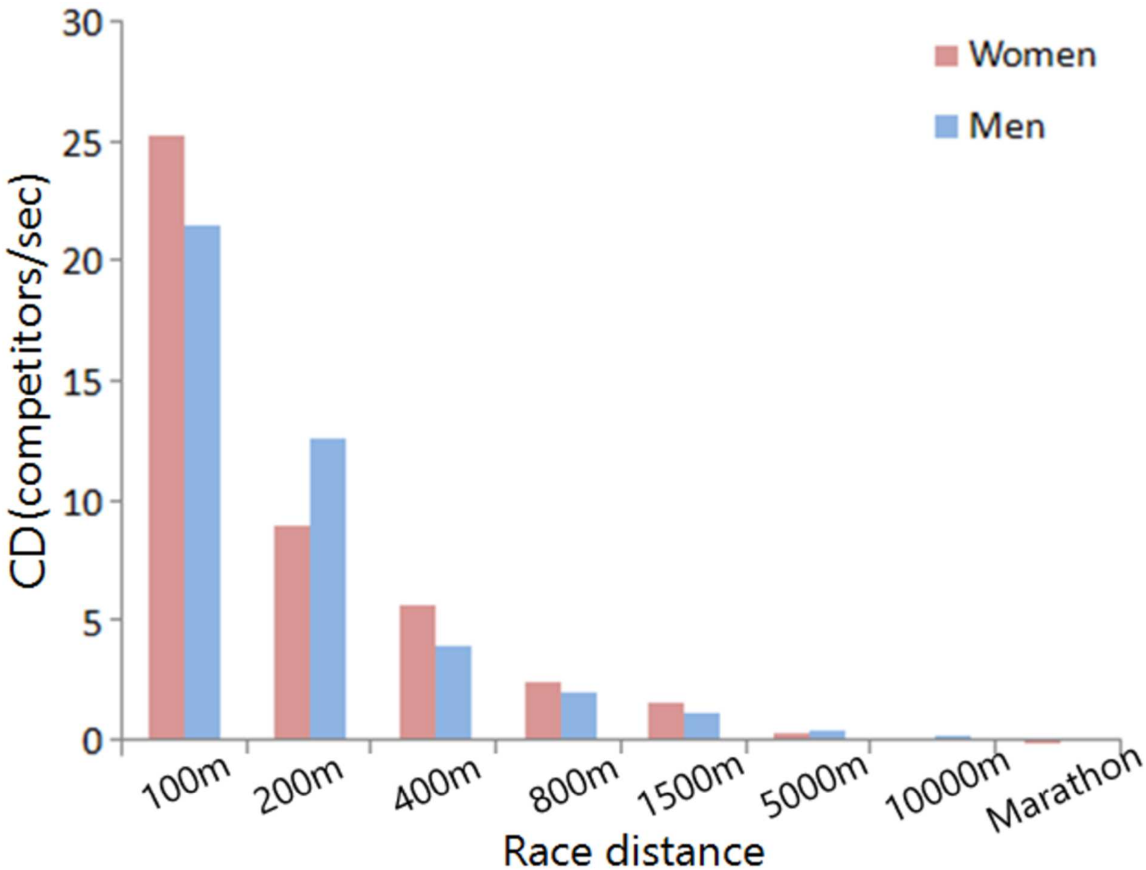

100m
200m
400m
800m
1500m
5000m
10000m
Marathon
Speed (km.h-1)
Calendar years
1975
1981
1987
1995
2001
2007
2013

Figure 5


CD (competitors/sec)
30
25
20
15
10
5
0
Women
Men
100m
200m
400m
800m
1500m
5000m
10000m
Marathon
Race distance

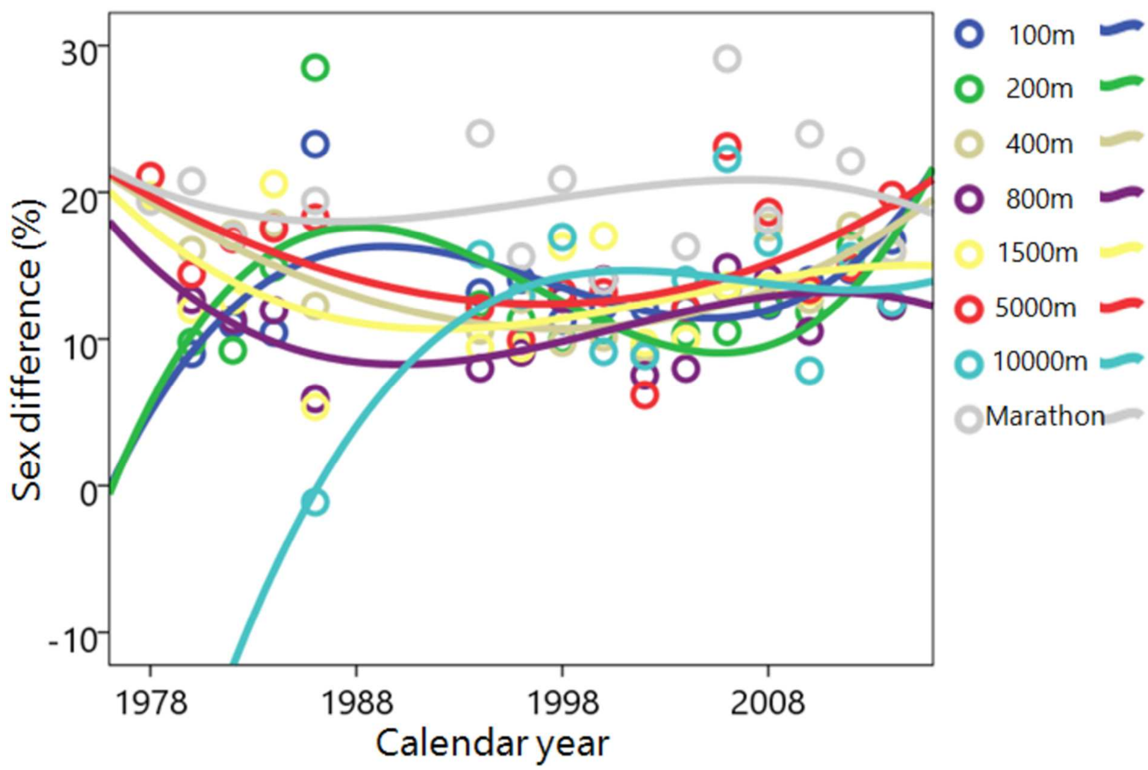


Figure S1 Sex difference in speed by race distance and calendar year.

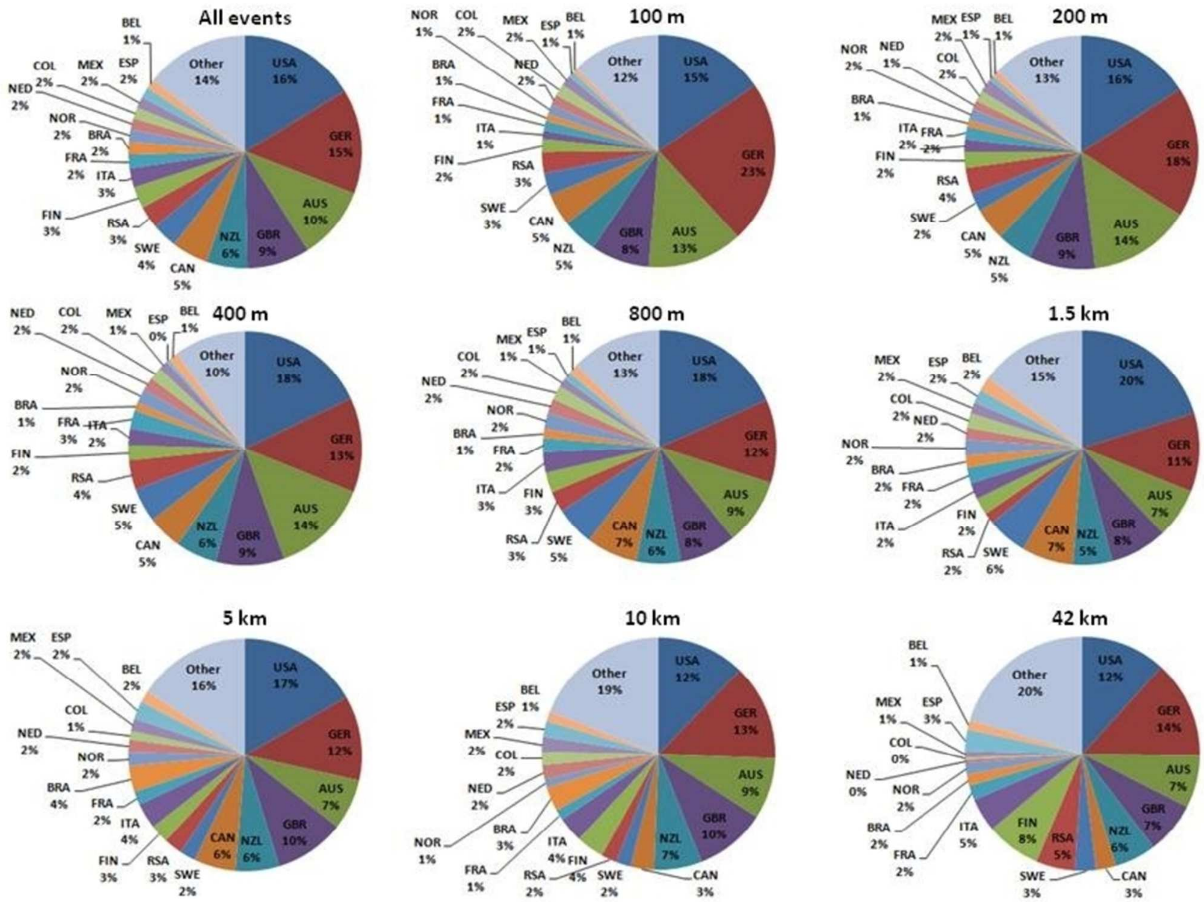


Figure S2 Distribution of women by nationality.

* Nationalities with at least 10 athletes in at least seven events are presented, whereas the rest are included in *Other*. USA=United States of America, GER=Germany, AUS=Australia, GBR=Great Britain, NZL=New Zealand, CAN=Canada, SWE=Sweden, RSA=South Africa, FIN=Finland, ITA=Italy, FRA=France, BRA=Brazil, NOR=Norway, NED=Netherlands, COL=Colombia, MEX=Mexico, ESP=Spain and BEL=Belgium.

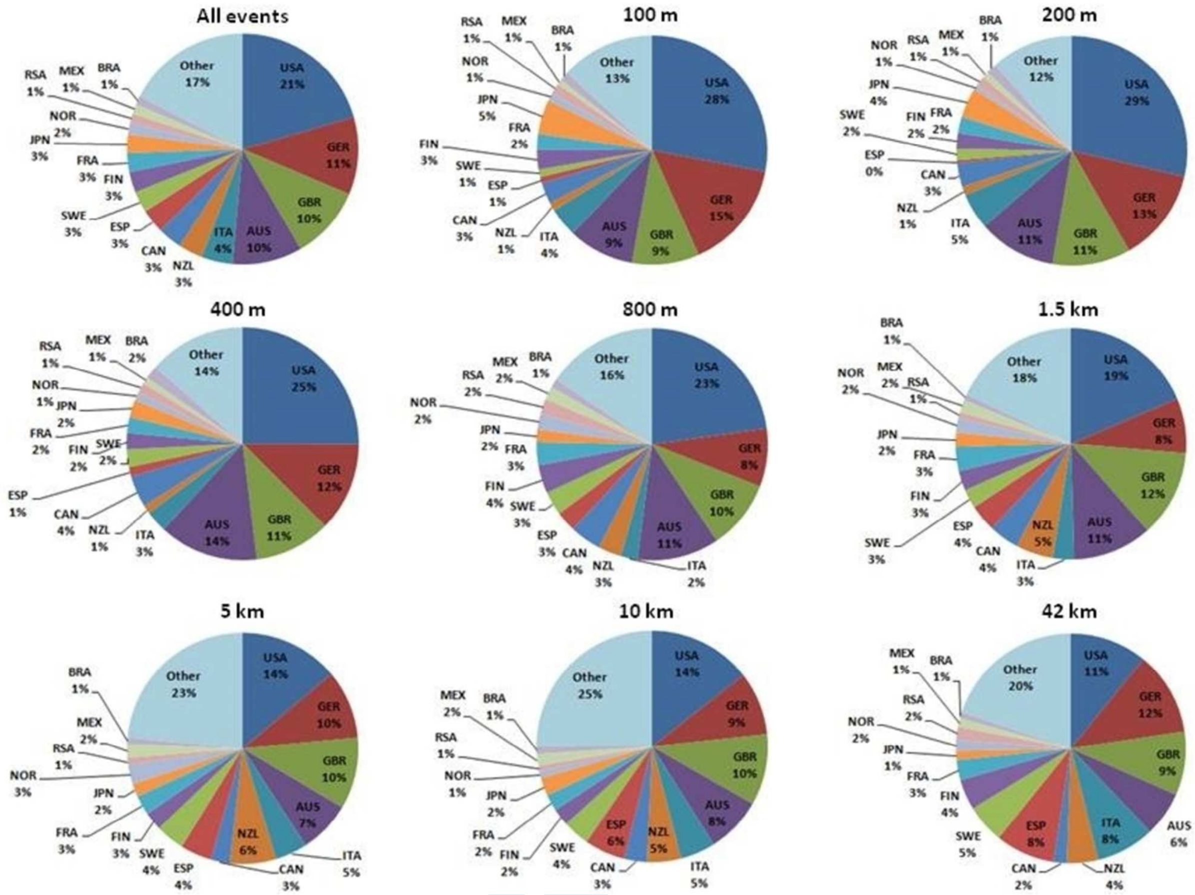


Figure S3 Distribution of men by nationality.

* Nationalities with at least 10 athletes in at least seven events are presented, whereas the rest are included in *Other*. USA=United States of America, GER=Germany, GBR=Great Britain, AUS=Australia, ITA=Italy, NZL=New Zealand, CAN=Canada, ESP=Spain, SWE=Sweden, FIN=Finland, FRA=France, JPN=Japan, NOR=Norway, RSA=South Africa, MEX=Mexico and BRA=Brazil.